2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

ELECTROSTATIC COALESCENCE FOR AERIAL SPRAY DRIFT MITIGATION

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Abstract

Electrostatic spray technology was pioneered for improved spray deposition. Many have thought that with improved spray deposition that there would also be reduced off-target deposits. Aerial electrostatic systems are now commercially available and more experience is being gained on the most appropriate uses for electrostatic systems in aerial application of crop protection and production products. When aerial electrostatic systems were configured for enhanced spray deposition, field studies did not show reduced spray drift. However, preliminary research indicated that an aerial electrostatic system configured for coalescence did increase the size of spray droplets deposited in the spray swath. This study was designed to determine if a similarly configured system with conventional spray rates would decrease drift and downwind spray deposits. The large-scale field study did not confirm the preliminary research.

Introduction

Electrostatic principles have been employed successfully in applications for enhanced on-target and reduced off-target deposition of sprays. Industrial applications of paint and other coatings are notable examples (Colbert 1982). Electrostatics has also been adapted to agricultural application of crop production and protection materials (Bowen et al., 1952; Bowen et al., 1964; Law, 1977; and Law and Lane, 1981). Successful commercial versions of electrostatic sprayers for greenhouse, ground, and orchard sprayers have been available for several years (Sherman and Bone, 1983; Matthews, 1989; Kabashima et al., 1995; Palumbo and Coates, 1996; Brown et al., 1997; and Sumner et al., 2000).

Aerial electrostatic application has also been a subject of research and development (Carlton and Isler, 1966; Threadgill, 1973; and Inculet and Fischer, 1989). But until recently, there was no commercial adaptation of electrostatics to aerial applications. Research and development over an extended period (Carlton, 1968; Carlton, 1975; and Carlton et al., 1995) culminated in a patent (Carlton, 1999) for an aerial electrostatic application system that is currently marketed by Spectrum Electrostatic Sprayers, Inc. (Dobbins, 2000). The prototype aerial electrostatic system was shown to deposit more active ingredient than conventional systems, but improved efficacy was not consistently reflected in controlled experiments (Kirk et al., 2001). There was speculation that since active ingredient deposits were enhanced, spray drift would be reduced. But, spray drift studies with the electrostatic system did not detect reduced downwind drift deposits. However, Kihm et al. (1991) showed that in-swath droplet size and deposits were significantly increased when an earlier version of the aerial electrostatic system was setup in coalescence mode as opposed to the enhanced deposition mode.

The conventional or enhanced deposition mode for aircraft as determined by Carlton (1999) has all the nozzles on one side of the aircraft charged positively and all the nozzles on the other side of the aircraft charged negatively. The design spray rate for the system was limited to 9.4 L/ha (1 gal/acre) to maintain an adequate charge-to-mass ratio to enhance spray deposition. The coalescence mode has adjacent nozzles with opposite charges on both sides of the aircraft. This arrangement would facilitate the adjacent and oppositely charged fine droplets to either merge into larger droplets or merge with larger droplets and consequently reduce the fine droplet component of the spray spectrum. The electrostatic coalescence mode could be more widely adopted if it were applicable to spray rates higher than 9.4 L/ha (1 gal/acre). The spray rate for this study was set at 25 L/ha (2.7 gal/acre). The increase in spray rate was expected to reduce the 1.2 mC/kg charge-to-mass ratio of the prototype system, yet still provide adequate charge to smaller droplets to enhance coalescence with larger droplets and consequently reduce spray drift.

Charge-to-mass ratio (Q/M) is a critical factor in electrostatic enhancement of agricultural aerial spray deposits. Inculet and Fischer (1989) showed only a marginal increase in electrostatic aerial spray deposition with a Q/M of 0.3 mC/kg. Carlton and Bouse (1980) with simulated aerial field deposition show relatively low increases in spray deposits as Q/M increases in the lower range, but dramatic increases in deposits with Q/M of 3.8 mC/kg or greater. Law and Lane (1981) in controlled laboratory studies with electrostatic spray rates of 9.4 L/ha (1 gal/acre) and Q/M from 2 to 8.2 mC/kg showed increases in deposits of 1.4 to 4.4 fold with electrostatic charging compared to conventional spray rates and similar uncharged sprays.

If electrostatic coalescence is effective, the process should reduce spray drift downwind of the application site. The objective of this study was to determine if aerial electrostatic coalescence would reduce spray drift from conventional aerial spray rates.

Materials and Methods

A field study was conducted to determine the effects of electrostatic charging conventional aerial spray rates with the aerial electrostatic system configured in coalescence mode. The prototype system, Figure 1, was installed on a Cessna AgHusky agricultural aircraft (Cessna Aircraft Corporation, Wichita, Kansas). Three treatments were included in the study: 1) the electrostatic system configured in coalescence mode with active charge, 2) the electrostatic system with no charge, and 3) a conventional boom with a conventional nozzle arrangement. The electrostatic boom and a conventional boom were interchangeable on the aircraft. Nozzle parameters on both booms were selected so that the spray rate for both systems was 25 L/ha (2.7 gpa). The aircraft was operated at 193 km/h (120 mph) with a 14 m (46 ft) swath width for all applications.

The treatments were all applied over the swath in a crosswind with two passes, one with the right wing on the upwind side and one with the left wing on the upwind side. The pilot was instructed to maintain height of flight over the spray swath at 1.5 m (5 ft) for all treatments. The spray mix was tap water plus 0.25% volume/volume Triton X-100 (VWR International, West Chester, Pennsylvania) plus 0.53 gm/L (2 gm/gal) Caracid Brilliant Flavine FFN fluorescent tracer (Carolina Color and Chemical Company, Charlotte, North Carolina). Fluorescent tracer deposits on mylar cards provide a measure of both in-swath and downwind drift deposits.

The field study was conducted in May 2002 at Texas A&M University Riverside Campus, Burleson County, Texas, in a pasture with grass mowed to a height of about 15 cm (6 in). The study incorporated the three treatments shown in Table 1.

Effort was made to apply all treatments in wind speeds of 1.8-4.5 m/s (4-10 mile/h). A weather station was placed upwind and adjacent to the swath and spray drift sample line. Wind speed and direction, temperature, and relative humidity were recorded at 2-m (6 ft) height. The field layout for the study is shown in Figure 2.

The in-swath sample locations, -S14, -S10.5, -S7, -S3.5, and S0, and the downwind drift/deposit sample locations, D2.5, D5, D10, D20, D40, D80, D160, and D320, were measured in meters from the downwind edge of the spray swath. Each sample location had a 10- X 10-cm mylar card and a 24- X 76-mm water-sensitive paper (WSP) sampler (WSP only on Replications 1 and 3) (Spraying Systems Co., Wheaton, Illinois). These two sample collectors were located on a 30- X 30-cm plywood sheet placed on the ground. Mylar card collectors and stable fluorescent tracers give good estimates of spray swath and drift deposits on planar surfaces. The WSP samples were removed from the sample line after one pass of the aircraft. The mylar cards were collected following two passes of the aircraft for each treatment. There were four replications of each treatment in a randomized block experimental design.

Spray and drift deposits were determined by procedures used in previous studies (Kirk et al., 2000). The mylar cards were placed in individual plastic bags and washed in 20 ml of ethanol. An aliquot of effluent was placed in 12- X 75-mm borosilicate glass culture tubes and fluorometric dye concentrations were obtained with a Shimadzu RF5000U Spectrofluorophotometer (Shimadzu Corporation, Kyoto, Japan). Spray deposits on the cards were quantified by comparison with similarly determined dye concentrations from spray tank samples. The mylar card data are expressed as quantity of dye deposited per unit area of the card. This analysis gives a relative deposit comparable to the amount of a pesticide active ingredient deposited per unit area. The WSP samples were placed in 35-mm negative sleeves and processed with computerized image analysis (IMAQ Vision Builder v5, National Instruments, Austin, Texas) to determine droplet stain density and stain size. Stain size, stain diameter, or minimum stain dimension (D_s in µm) was determined for each stain in two 1.5-cm^2-sample areas on each card. Each stain in the sample area was converted to droplet diameter (D_d in µm) with the experimentally determined equation for a spray mix of tap water plus 0.25% v/v Triton X-100:

$$D_d = 0.535\ D_s - 8.484E\text{-}05\ D_s^2$$

Percent coverage, droplet density, and droplet size were subsequently determined for each WSP card.

Statistical analyses of the data were conducted with SAS STAT procedures (SAS 2001). The data were analyzed as repeated measures by distance using the Mixed procedure. The wind vector parallel to the sampling line was used as a covariate to account for deviation in wind velocity and direction for each treatment replication. Treatment differences were assessed by Fisher's F. Significance levels are stated with the data presentations.

Results and Discussion

Weather Conditions

This study was conducted under relatively consistent temperature conditions, averaging 30°C (86°F) with standard deviation of 1.3°C. Relative humidity ranged from 48% to 71%. Wind speed and direction were also reasonably stable. Five-minute averages at the 2 m (6 ft) height when the two spray swaths were made for each treatment replication ranged from 15 to 21 km/h (9 to 13 mile/h) with deviations from parallel with the spray sample line averaging only 5.5° with a range of -3° to -20°. No treatment replications exceeded deviations >±30° according to ASAE Standard S561 JUN98 (ASAE Standards, 2000) so no data were excluded from the analyses.

Spray Deposition and Drift

Mylar Card collections of spray and drift deposits, averaged by treatment for each sampler location, are shown in Table 2. Graphical display of these data is helpful in better understanding the treatment responses. However the range of spray deposits, within the spray swath to far-field drift deposits, is so wide that a single graphical display of the data does not show adequate detail. Deposits in the spray swath and immediately beyond – the displaced swath – are shown in Figure 3. It is apparent that the crosswind moved the spray deposit pattern downwind about 1/2-swath. There is considerable variability in the spray deposits in the swath from treatment to treatment, but the near-field downwind deposits from the three treatments, Figure 4, are remarkably similar. The treatment with conventional D6-46 nozzles had slightly higher deposits in the far-field downwind. However, there was no significant difference between the treatments for downwind drift deposits $(p > F) = 0.93$.

Water Sensitive Paper (WSP) sample data are generally less reliable in quantifying deposit parameters than mylar cards, primarily because sample sizes are significantly smaller and small experimental errors are magnified in calculated projections to larger surfaces. However, there are certain parameters that are quantifiable on WSP that are not quantifiable on mylar cards. Data for these parameters are presented in Table 3. WSP cards from the electrostatic coalescence treatment showed small deposits on the two most-upwind sampler sites which were not observed with the other treatments, and there were no deposits observed at D160 and D320 for this treatment. The other treatments had deposits on WSP at D320 but not at D160; these observations may represent an anomaly since it is not expected that there would be deposits at D320 but not at D160.

Percent Coverage. The percent of the WSP card area covered with spray droplet stains (percent coverage) was variable by location in the swath and downwind. There were trends for percent coverage to be higher at the two most upwind locations in the swath and lower for the downwind locations for the Electrostatic ON treatment, but overall coverage trended lower for all Electrostatic ON treatment locations. However, these trends were not significant in the swath, $(p > F) = 0.79$ or the downwind drift sample locations, $(p > F) = 0.32$.

Droplet Density. The number of droplet stains per unit area, or droplet density, expressed similar but less consistent trends as observed for percent coverage. There were no significant differences in droplet densities between treatments either in the swath $(p > F) = 0.68$ or downwind $(p > F) = 0.12$.

Droplet Size. Spray droplet size computed from stains on WSP was similar for the Electrostatic ON and the Electrostatic OFF treatments, except for deposits detected at the two most upwind sample locations in the swath and the droplet stains observed at the most downwind location; however these differences were not statistically significant for samples either in the swath $(p > F) = 0.14$ or downwind $(p > F) = 0.15$.

Summary

Electrostatic systems have demonstrated considerable promise for increased spray deposits, reduced spray drift, and improved efficacy. However, these benefits appear to be marginal when applied to high-speed aerial operations, even when spray rates are limited to 9.4 L/ha (1 gal/acre). However, 9.4 L/ha (1 gal/acre) capability, with performance equivalent to 28 to 47 L/ha (3 to 5 gal/acre) as reported by Kirk et al. (2001), provides significant benefit to the aerial applicator in operational efficiency. The apparent limiting factor in the expected increased effectiveness of aerial electrostatic systems is maintenance of a high charge-to-mass ratio on the spray droplets released from the aircraft. This factor is limiting with the current prototype electrostatic system because of the spray nozzle flow rates required to maintain reasonable field spray rates at aircraft speeds. The charge-to-mass ratio for the aerial electrostatic coalescence system used in this study was at lower levels than the prototype design to achieve a 25 L/ha (2.7 gal/acre) spray rate. However, the concept of electrostatic coalescence for preferentially charging the driftable fine droplets was neither sufficient to reflect increased droplet sizes in the swath nor to significantly reduce downwind spray drift at conventional aerial spray rates.

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Table 1. Three treatment setups for electrostatic coalescence spray drift study.

Boom	Electrostatic Charge	Spray Pressure, kPa (psi)	Nozzle* Number and Identification
Electrostatic System	On	480 (70)	27 Pairs SS TX-VK26, 50 mesh screen
Electrostatic System	Off	480 (70)	27 Pairs SS TX-VK26, 50 mesh screen
Conventional	None	275 (40)	27 D6-46 Straight Back, Slotted Screen

*Nozzle orifices by Spraying Systems Co., Wheaton, Illinois

Table 2. Spray and drift deposits (μg/cm^2) on mylar cards for the three treatments at thirteen sampler locations.

	Distance from downwind edge of the swath, m												
Treatment	-S14	-S10.5	-S7	-S3.5	S0	D2.5	D5	D10	D20	D40	D80	D160	D320
Electrostatic ON	0.00025	0.0673	0.1729	0.2108	0.1608	0.2193	0.1789	0.0829	0.0414	0.0104	0.0027	0.00027	0.00029
Electrostatic OFF	0.00022	0.0002	0.0994	0.1441	0.1380	0.1837	0.2290	0.0942	0.0416	0.0139	0.0032	0.00018	0.00067
Conventional	0.00014	0.0018	0.1581	0.1640	0.1080	0.2216	0.2261	0.0801	0.0371	0.0103	0.0074	0.00289	0.00634

Table 3. Three water sensitive paper data parameters for three treatments at thirteen sample locations (Coverage, %; Droplet Density, Number/cm^2; and Volume Median Diameter, μm).

	Distance from downwind edge of the swath, m												
Treatment	-S14	-S10.5	-S7	-S3.5	S0	D2.5	D5	D10	D20	D40	D80	D160	D320
	Coverage, %												
Electrostatic ON	0	3	6	6	9	8	6	2	0	0	0	0	0
Electrostatic OFF	0	0	6	9	10	10	10	7	2	2	1	0	0
Conventional	0	0	9	7	10	11	14	8	2	1	1	0	0
	Droplet Density, number/cm^2												
Electrostatic ON	0	7	25	25	28	29	23	15	6	3	1	0	0
Electrostatic OFF	0	0	18	29	38	32	42	27	15	8	2	0	1
Conventional	0	0	14	15	27	26	28	32	8	6	2	0	1
	Volume Median Diameter ($D_{v0.5}$), μm												
Electrostatic ON	16	129	226	221	197	213	170	165	132	129	37	0	0
Electrostatic OFF	0	0	237	216	187	204	188	204	105	193	118	0	96
Conventional	0	0	306	238	242	250	236	203	179	169	121	0	16

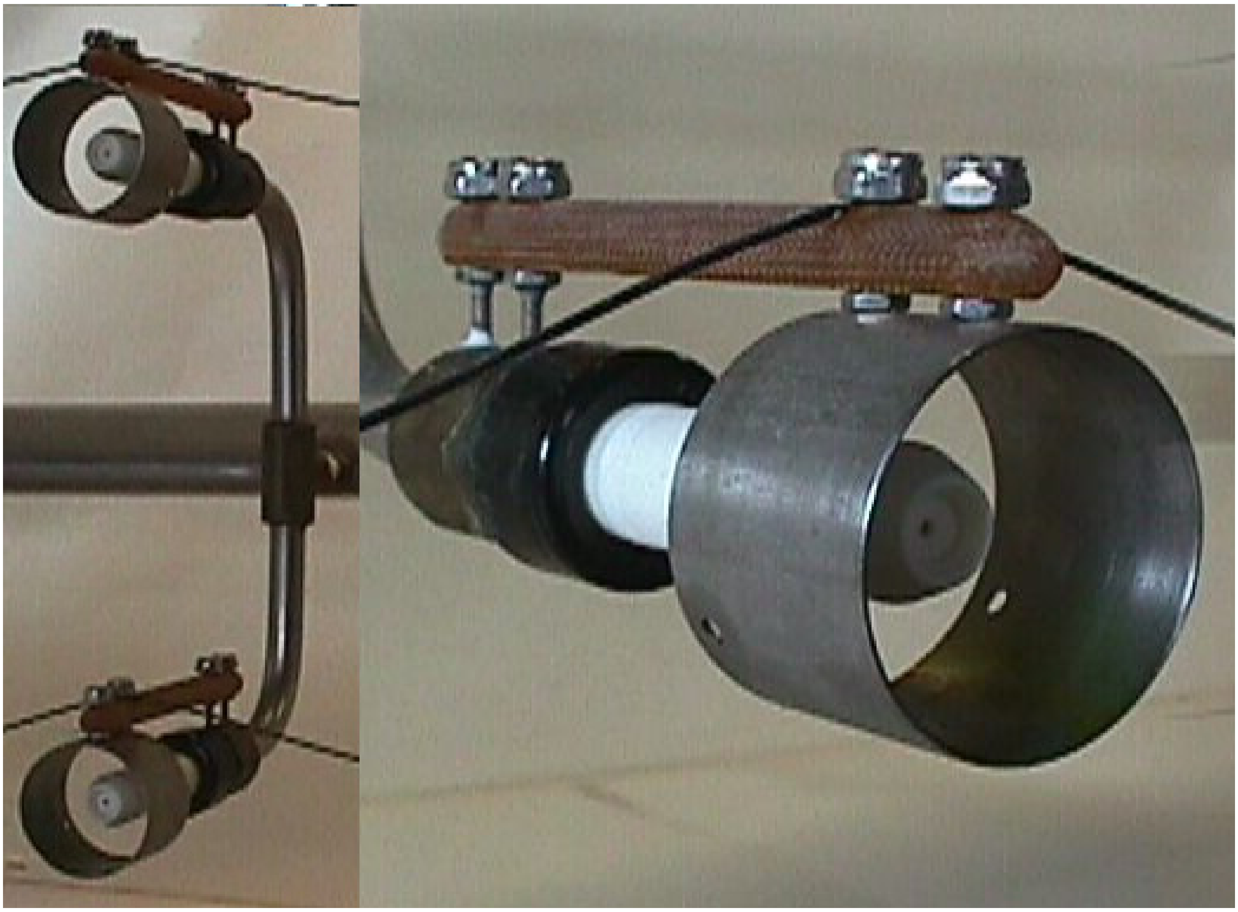

Figure 1. Electrostatic spray nozzle. Note inset that the nozzles are mounted on the boom in pairs with one nozzle with positive charge and one nozzle with negative charge.

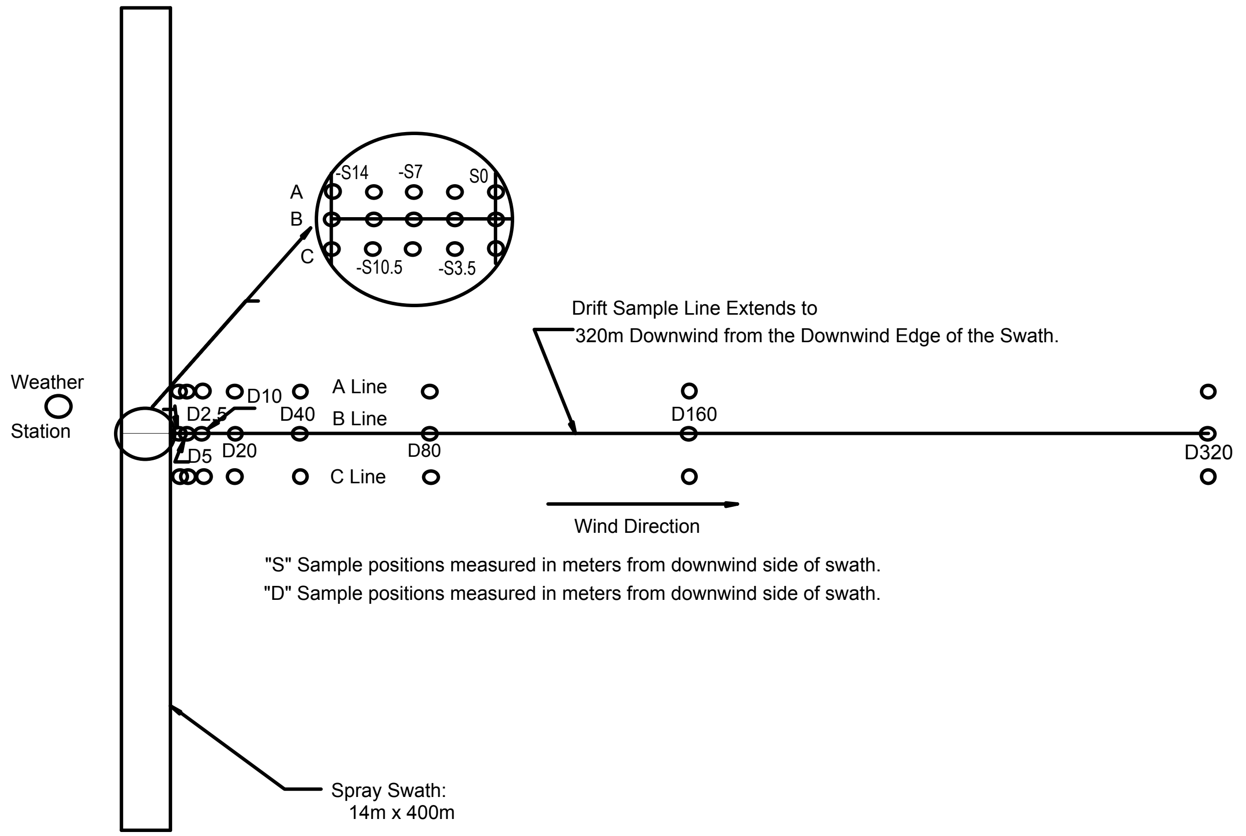

Figure 2. Field layout for aerial electrostatic coalescence spray drift study.

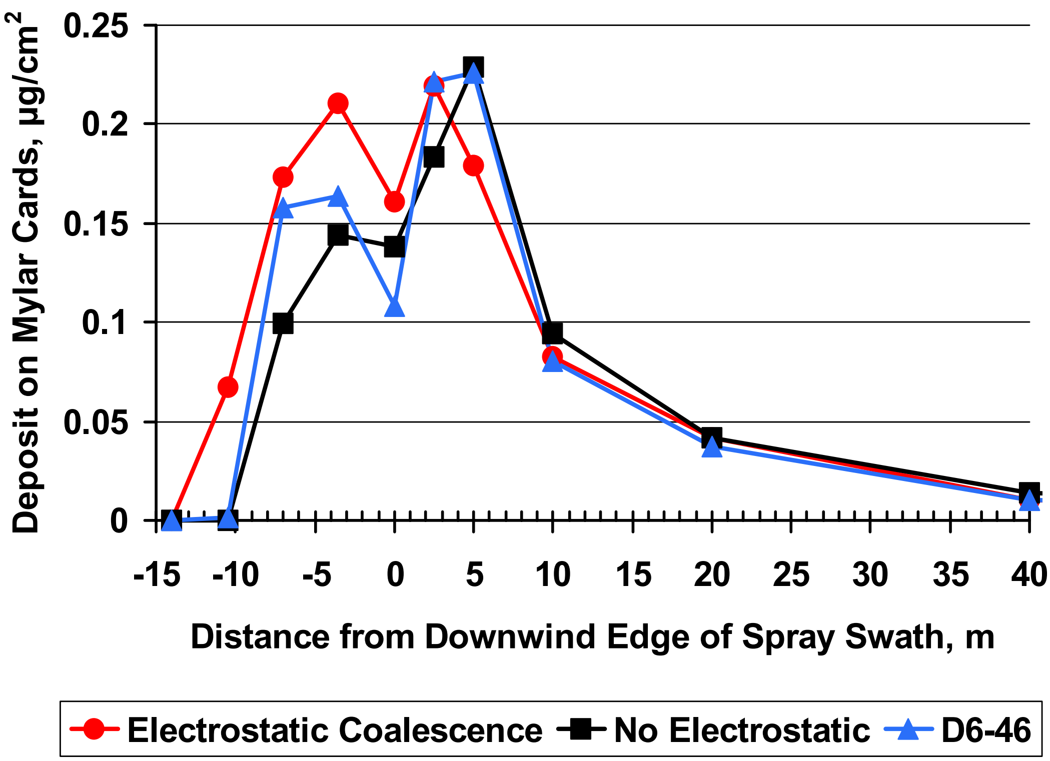

Figure 3. Displaced swath and near-field spray deposits.

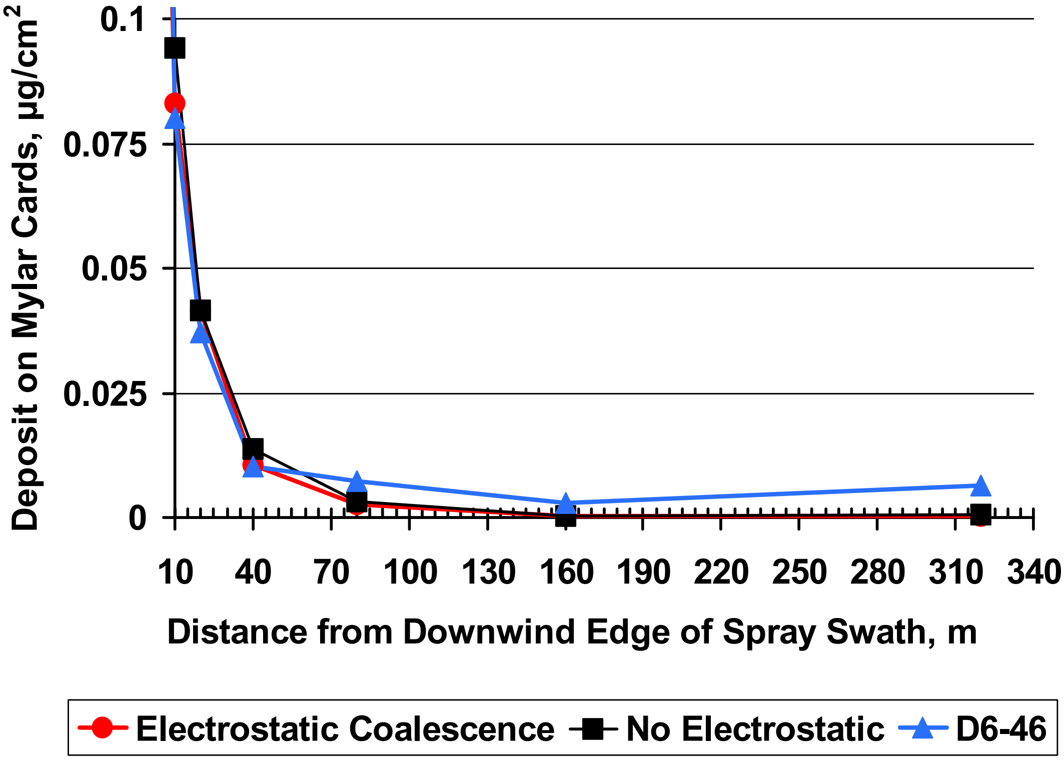

Figure 4. Downwind spray drift deposits.